— 研究論文 —
Scientific Papers

Glacio-Geomorphological Observations in Cape Omega on the Prince Olav Coast, East Antarctica

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東南極オメガ岬の地学的観察

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要旨: 第18次南極地域観測隊オメガ岬調査に参加し，次の観察を行った．オメガ岬は，昭和基地付近の他の露岩と同様，氷河作用を受けたいくつかの特徴を有する．過去の氷床はオメガ岬全域を覆っていた．擦痕は異なる方向の2群に分けることができ，これから，過去の氷の流動は，より古い SE-NW 方向からより新しい ESE-WNW 方向へ変化したこと，露岩域の風化程度などから，氷からの解放は北部がかなり早く，氷の後退はゆっくりと行われたことが知られる．ただし，露岩上へのモレーン堤の形成はみられない．露岩背後のモレーン堤は，昭和基地付近では最大級であるが，厚くなく，剪断モレーンである．モレーン堤や露岩上の氷成堆積物には構造土の発達が顕著である．構造土での地温測定の結果，最低温度も氷点下には下がらなかったが，この時期がたまたま異常高温であったためと考えられる．大陸氷縁辺部での融氷水流も顕著で，流量測定の結果，水流1本で 6×10^3 t/day 以上の値が得られた．

Abstract: The reconnaissance geomorphological survey of Cape Omega was made by the author in January 1977. Cape Omega has glaciated features same as other ice-free areas in the vicinity of Syowa Station. The past ice sheet had covered Cape Omega completely. Abundant glacial striae are preserved on the bedrock, and they are classified into two groups, *i.e.* SE-NW trending ones and ESE-WNW trending ones. The former group indicates the older direction of ice flow, and the latter indicates the younger. Judging from the degree of weathering of the bedrock, the northern part of Cape Omega was freed from the ice sheet earlier than the southern part. The moraine in the marginal part of the ice sheet close to the rocks is the biggest one among those in the vicinity of Syowa Station. Patterned ground develops well on the moraine bank and on the glacial deposits on the rocks.

Measurement of earth temperature in the sorted polygon was made for 2 days. Measured minimum temperature did not fall below freezing point. It

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may be ascribed to some extent to the fact that the period of measuring was abnormally high temperature period near Syowa Station. In the summer season, meltwater streams occur in the marginal zone of the ice sheet. Several meltwater streams develop in a zone of 2.5 km in width in the Cape Omega area. Measurement of flow rate was made at one of those, and the amount of flow of the meltwater stream was calculated to be over 6×10^3 t/day.

1. Introduction

Cape Omega is located at 41°05′S on the Prince Olav Coast (Fig. 1). It is composed of several small bare rocks and a row of moraine bank, and it was named by the wintering party of the first Japanese Antarctic Research Expedition (JARE-1) which traveled along the Prince Olav Coast (NISHIBORI, 1958; HARADA, 1964). These small rocks were divided into three groups, and they were named Omega-higasi Rock, Omega-naka Rock and Omega-nisi Rock according to arrangement from east to west (NATIONAL INSTITUTE OF POLAR RESEARCH, 1979).

The first survey of Cape Omega was made by the members of JARE-10 (YOSHIDA, 1978). The second survey was carried out from 5th to 10th January 1977 by a four-

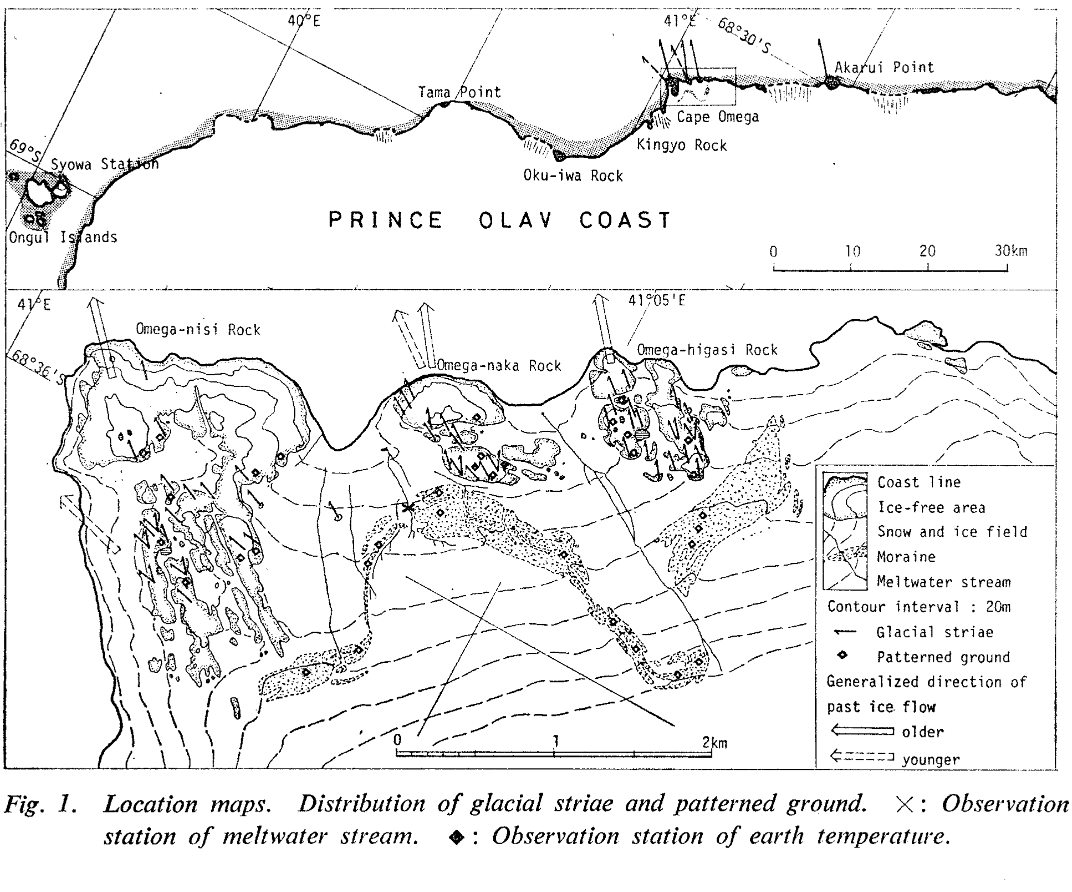

Fig. 1. Location maps. Distribution of glacial striae and patterned ground. ×: Observation station of meltwater stream. ◆: Observation station of earth temperature.

man party of JARE-18 consisting of S. OHTAKI (Geodesy), M. SUZUKI (Geology), F. FUKUI (Geochemistry) and the present author (Geomorphology). The main purposes of this survey were the geological and geodetic surveys. The geomorphological observation was made also by the author as an additional program. The results of the geological survey were published already (SUZUKI and MORIWAKI, 1979; SUZUKI, 1979) and the result of geodetic work is in press as 1/25000 topographic map by the Geographical Survey Institute, Japan.

2. General Topography

The bedrock of Cape Omega is composed mainly of granite, gneiss and metabasite (Fig. 2).

The topography of bare rocks is the plateau lower than 100 m in height with the slightly undulating surfaces and the relatively steep marginal slopes facing on the sea. This feature is typical in Omega-nisi Rock (Fig. 3). The slightly undulating surface is composed of ridges and depressions with relative height of 10–20 m. Rises on these ridges are composed of resistant granitic rocks. Similarly to other ice-free areas near Syowa Station, the directions of ridges and depressions of Cape Omega

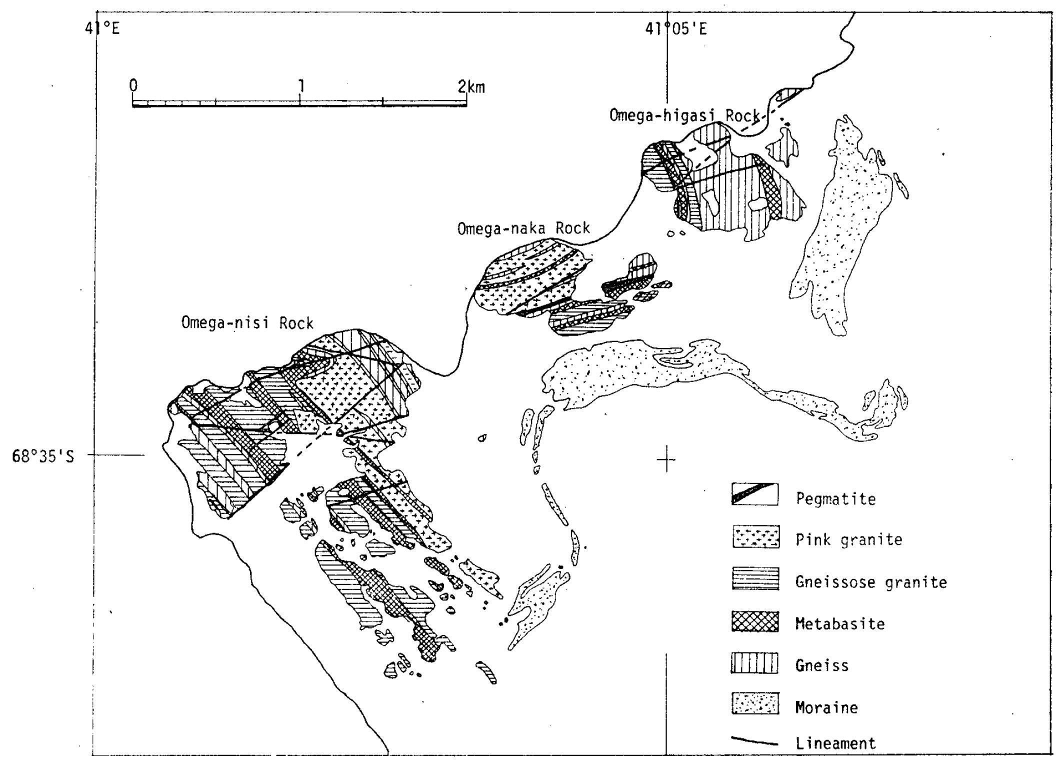

Fig. 2. Geological map slightly supplemented (after SUZUKI and MORIWAKI, 1979).

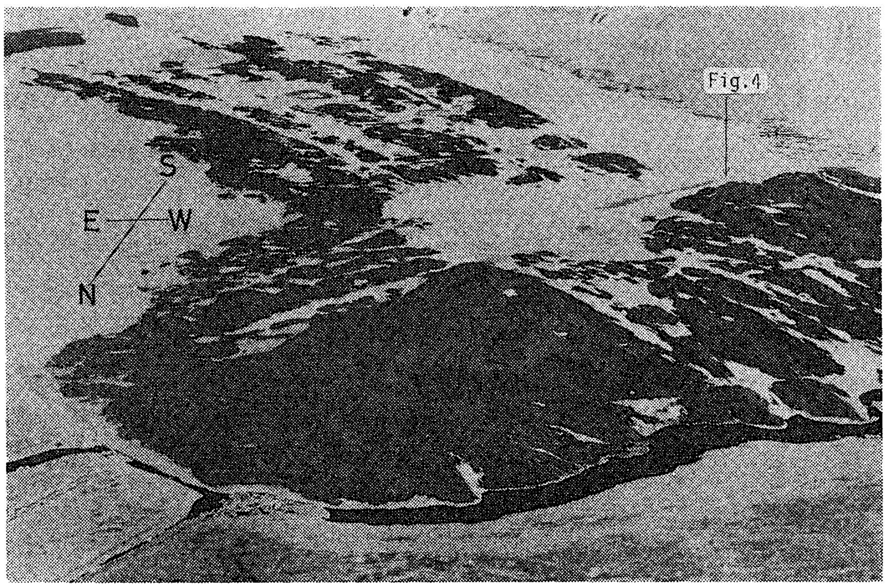

Fig. 3. Aerial photograph of Omega-nisi Rock.

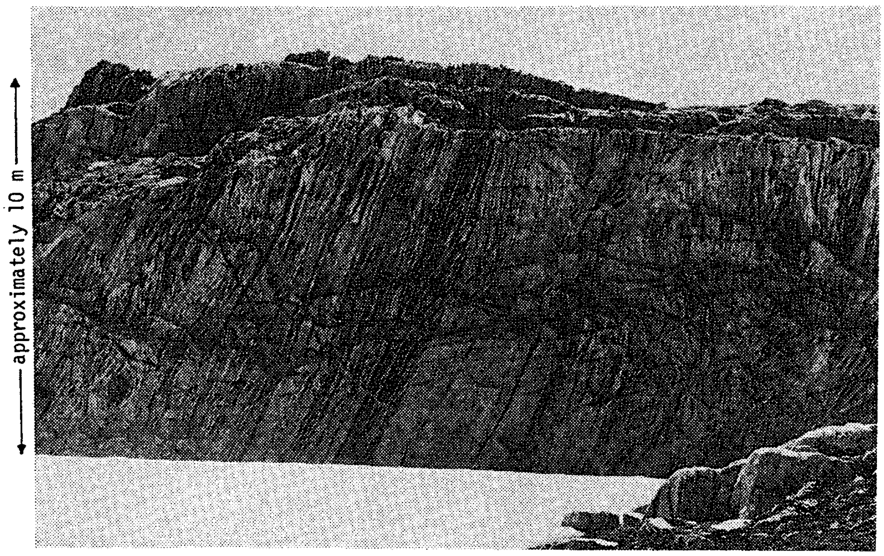

Fig. 4. NE-SW trending cliff in Omega-nisi Rock, shown in Fig. 3.

are concordant with those of the geologic structure of the bedrock. Namely, they trend NW-SE in Omega-nisi Rock, E-W in Omega-naka Rock and NNW-SSE in Omega-higasi Rock. Cliffs and depressions crossing those directions rectangularly or diagonally are notable too, and they reflect the joint system of the bedrock. Such characters of topography are obvious in the plan of bare rocks (Figs. 1, 2 and 4).

The rocks were also subjected to subaerial mechanical weathering. Especially in the northern part not only the bedrock but also the erratic boulders show honeycomb-weathering. However, the ice-smoothed surfaces are preserved partly on the granitic rocks even there.

It is apparent that Cape Omega was once covered completely with the ice sheet, since glaciated rocks and erratic boulders are distributed there. Glacial striae also remain in many places, though they are less developed in the northern part where the weathering is dominant than in the southern part. Most of small and shallow depressions of bedrock are overlain by glacial deposits.

Raised beaches lower than 30 m are developed in many ice-free areas on the east coast of Lützow-Holm Bay and the Prince Olav Coast (YOSHIDA, 1971; YOSHIDA and MORIWAKI, 1979). These beaches are composed mainly of gravel and sand derived from glacial deposits. In Cape Omega, as the sea-facing steep slopes are not covered by glacial deposits on their lower part less than 20–40 m high, raised beaches composed of materials derived from those are not developed. Raised former erosional shoreline like wave-cut terrace was not found in this area.

Behind the bare rock areas of Cape Omega, the moraine bank is developed with 5.2 km in length and 380 m in maximum width. It shapes the Greek letter "Ω". However, Cape Omega was not named owing to its shape but the form of rocks and moraine bank as a whole which were viewed from the sea.*

Patterned grounds are developed well on the moraine bank and on the glacial deposits in depressions.

3. Glaciation

As previously mentioned, Cape Omega was covered completely with the ice sheet sometimes in the past. Glacial striae are more dominant in the southern part than in the northern part. Since in Omega-nisi Rock and Omega-higasi Rock the geology of the bedrock is not different between its northern and southern parts, the difference in the preservation of glacial striae is not due to lithology but to the duration of subaerial weathering after deglaciation. This fact suggests that the ice retreated very slowly from north to south, thence the northern part of Cape Omega has been subjected to weathering considerably longer than its southern part, and has lost most of glacial striae. Recessional moraine indicating the stagnancy of ice retreat was not found on the rocks. The directions of glacial striae were measured at 59 positions, and are divided into two groups, *i.e.* SE-NW direction group and ESE-WNW direction group. In the same places were found striae of two different directions (Figs. 1 and 5).

* Dr. T. KITAMURA, Kyushu University, who proposed the name of Cape Omega (private communication).

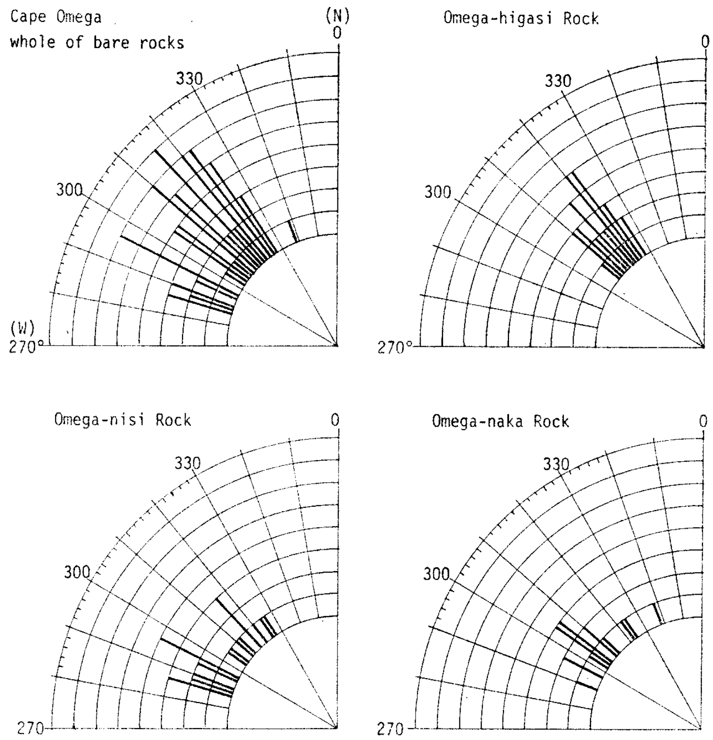

Fig. 5. Directions of glacial striae.

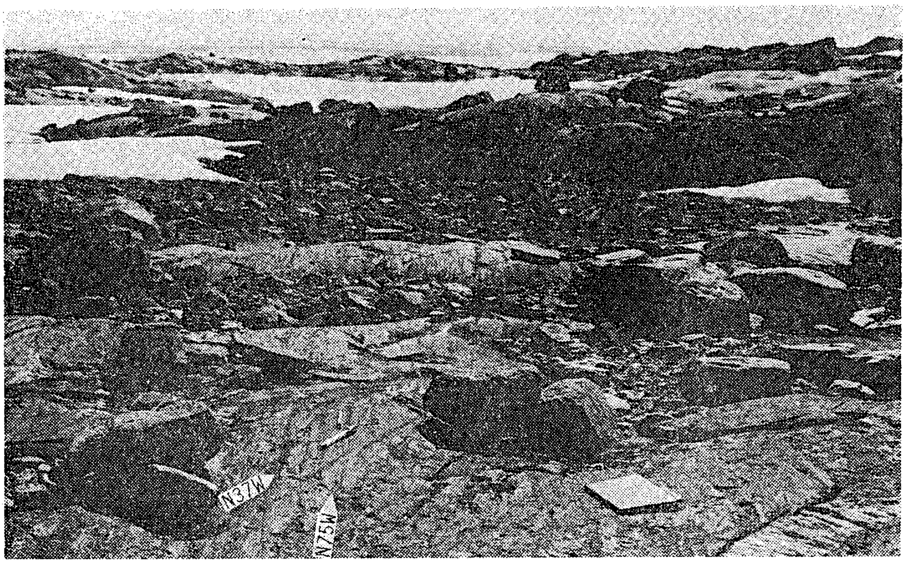

Fig. 6. Crossed glacial striae (N37W: older and N75W: younger) in Omega-nisi Rock.

In some places glacial striae indicate the divergent movement of ice (MORIWAKI, 1976). However, the obviously crossing striae suggest that the direction of ice movement changed. Such crossing striae are observed often in Cape Omega, especially in Omega-nisi Rock (Figs. 1 and 6). Younger striae can be distinguished often fairly well, because they are fresher than the older ones. In the case of Cape Omega, SE-NW trending striae are older than ESE-WNW trending ones. From this fact the history of ice movement is inferred as follows:

In the past glacial maximum, the ice sheet filled the bay north of Cape Omega—Kingyo Rock—Oku-iwa Rock—Tama Point, and flowed northwestward crossing rectangularly the past coast line located to the north of and parallel to the line connecting Akarui Point—Cape Omega—Tama Point.

In the next stage, the ice sheet retreated to around the present coast line and the above-mentioned bay was freed from the ice sheet. Then the flow of ice near Cape Omega—Kingyo Rock changed in direction from NW to WNW. Such change of ice flow was larger in the area of Omega-nisi Rock close to the bay than in the area of Omega-higasi Rock rather distant from the bay (Figs. 1 and 5).

In the latest stage, the ice sheet has retreated slowly to the present position. The moraine bank behind the rocks has been formed fairly late.

This moraine bank is the biggest among those in the vicinity of Syowa Station. The thickness of the moraine laid on the ice is about 1 m at banks of meltwater streams cutting the moraine bank. It is not much different from the thickness of other moraines which were observed near Syowa Station (MORIWAKI, 1976; SUZUKI and MORIWAKI, 1979). It suggests that this moraine is a shear plane moraine. Three or four stripes running parallel to the moraine bank exist on it. They suggest that the moraine bank is a recessional one which is composed of glacial materials freed from the shear plane due to the retreat of the ice sheet from the inner margins of bare rock.

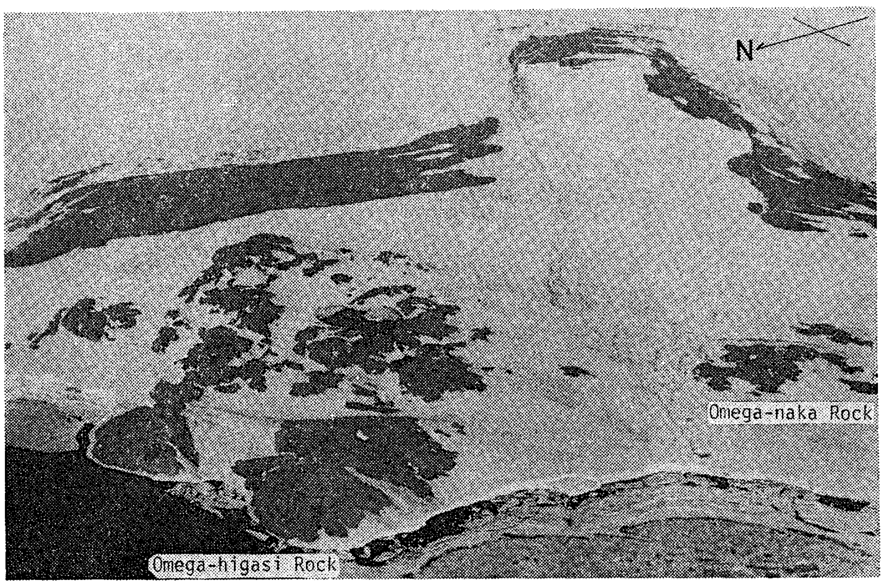

Fig. 7. Striped moraine bank and meltwater stream.

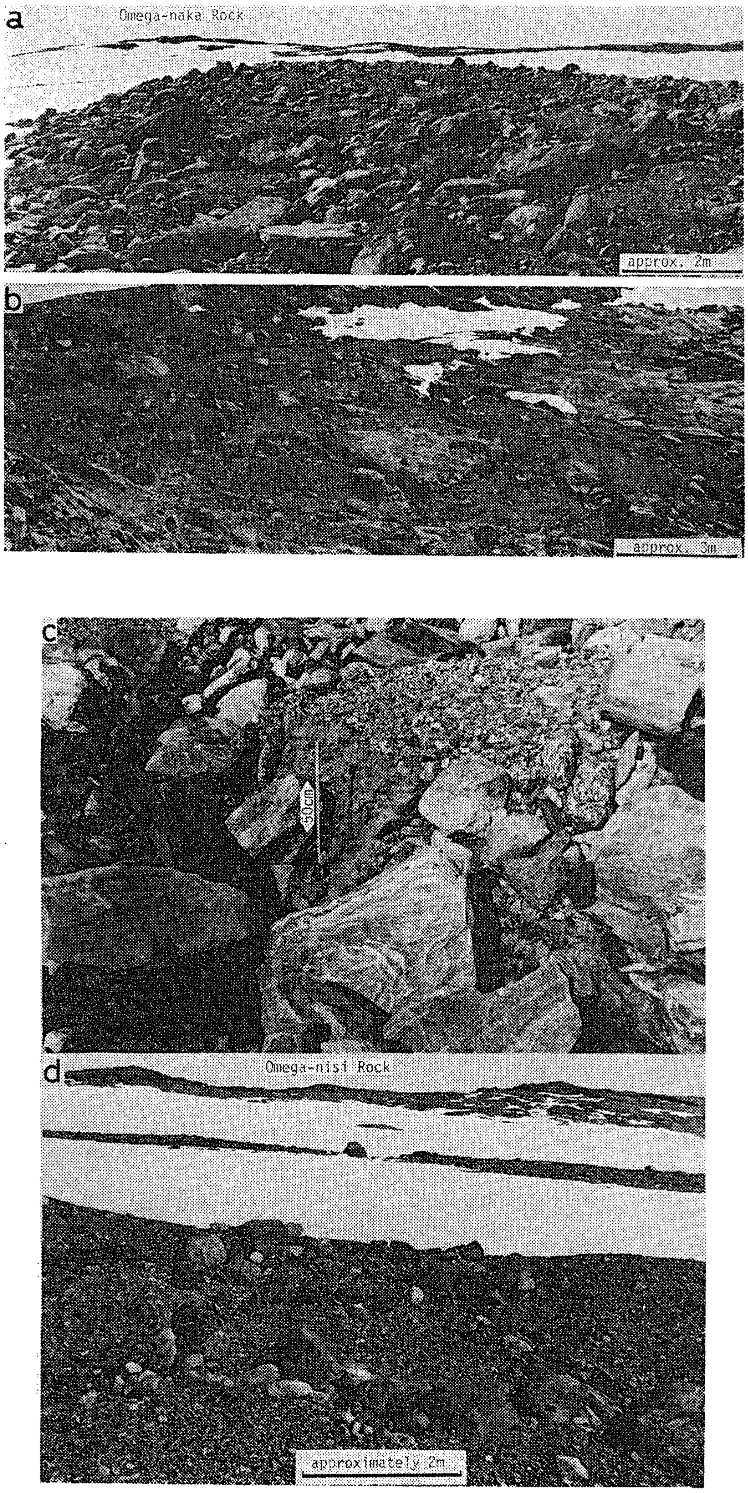

Fig. 8. Patterned ground. (a) Sorted circles in the moraine bank. (b) Sorted polygon in the glacial deposit in the depression of bedrock. (c) Sorted polygon eroded by meltwater on the moraine bank. (d) Polygonal network of contraction crack, which may be classified sorted polygon influenced by sorting.

areas (KOAZE, 1964; YOSHIDA, 1973; Figs. 1 and 7).

The top layer of the moraine consists of gravel and does not contain fine materials smaller than silt size (Fig. 8). It seems that fine materials were removed from the top layer by meltwater and wind in the summer season. From the development of sorted polygons on the moraine, it is considered that gravel was concentrated in the top layer due to sorting by freeze-thaw.

4. Periglacial Phenomena

Patterned ground and rock fragments produced by frost shattering are observed in Cape Omega. Rock fragments are not abundant so that they do not cover completely the bedrock slopes but are scattered on slopes.

Patterned grounds develop well on the moraine bank and on glacial deposits in depressions of the ice-free area (Figs. 1 and 8). They are sorted polygons (sorted circles), sorted steps and contraction cracks, sorted polygons being predominant among them. The diameter of sorted polygons ranges from 1 m to 5 m. Since bigger gravel was concentrated in contraction cracks, it is clear that sorting of gravel by freeze-thaw works there (Fig. 8d).

Patterned grounds develop well in the ice-free areas close to the ice sheet, *e.g.* Cape Hinode, compared with those in other ice-free areas rather distant from the ice sheet, *e.g.* the Ongul Islands. In the continuous measurement of earth temperature

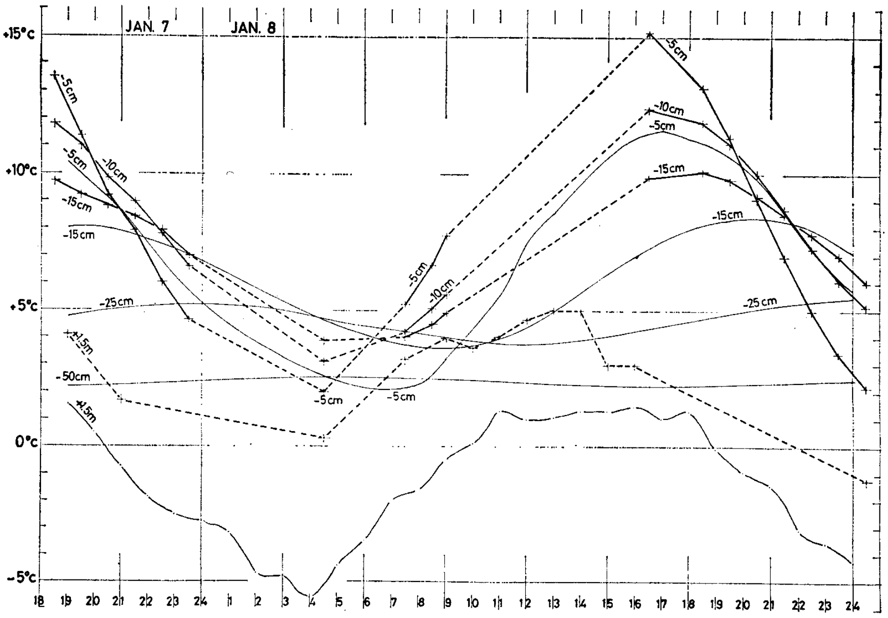

Fig. 9. Earth and air temperature. Thick line: Cape Omega (1977). Fine line: Syowa Station (1975).

Table 1. Meteorological data at the Syowa Station (THE JAPAN METEOROLOGICAL AGENCY, *1977, 1978a, 1978b, 1979*).

		Mean temperature			Maximum temperature		Minimum temperature		Mean amount of cloud	
		1975	1977		1975	1977	1975	1977	1975	1977
January	7	−1.5°C	+2.7°C		+1.5°C	+7.2°C	−4.8°C	−1.6°C	8.3	3.0
January	8	−2.3	+1.8		+1.1	+6.6	−5.7	−1.9	2.5	0.5
		1974 −75	1976 −77	1957 −77	1974 −75	1976 −77	1974 −75	1976 −77	1974 −75	1976 −77
December	11–20 mean	−1.1	+0.1	−1.7	+1.9	+3.5	−4.1	−3.4	5.6	5.1
	21–31 mean	−1.4	+0.6	−0.5	+1.6	+4.5	−4.6	−3.9	5.9	2.2
January	1–10 mean	−1.1	−0.3	−0.7	+2.3	+3.7	−4.8	−3.4	4.6	5.9
	11–20 mean	−0.0	+1.5	−0.4	+3.3	+5.2	−3.4	−2.5	5.4	3.2
	21–31 mean	+0.3	+1.4	−0.9	+3.3	+4.8	−2.7	−1.8	3.7	6.4

from February 1974 to January 1975 at Syowa Station in East Ongul Island, freeze-thaw cycles of water in soil occurred only a few times. The difference of development of patterned ground in both areas is presumably ascribed to the frequency of the freeze-thaw cycle (MORIWAKI, 1976).

Earth temperature was measured 18 times in 30 hours on the sorted polygon in Omega-naka Rock to confirm this presumption (Figs. 1 and 9), but the freeze-thaw cycle was not observed even at the uppermost horizon of soil. It may have been cause by relatively high air temperature in that summer season compared with the average one and in the summer of 1975 (Table 1 and Fig. 9), though the term of measurements was too short to get any definite conclusion.

5. Measurement of the Flow Rate of the Meltwater Stream in the Marginal Zone of the Ice Sheet

On the slope of the marginal zone of the ice sheet, numerous rills of meltwater from ice and snow are developed in every summer season. In Cape Omega, the melting is notable on the slope behind the moraine bank. Most of meltwater is dammed up once by the moraine, and then flows through gaps and depressions of the moraine bank (Figs. 1 and 10). A part of meltwater flows under the morainal deposits. There are several streams on slopes downward from the moraine bank to the extent of 2.5 km. Flow rate was measured in a medium-sized stream located in the center of the area (Fig. 1).

The measurements were made at intervals of 1 hour from 10:00 to 24:00 on Janu-

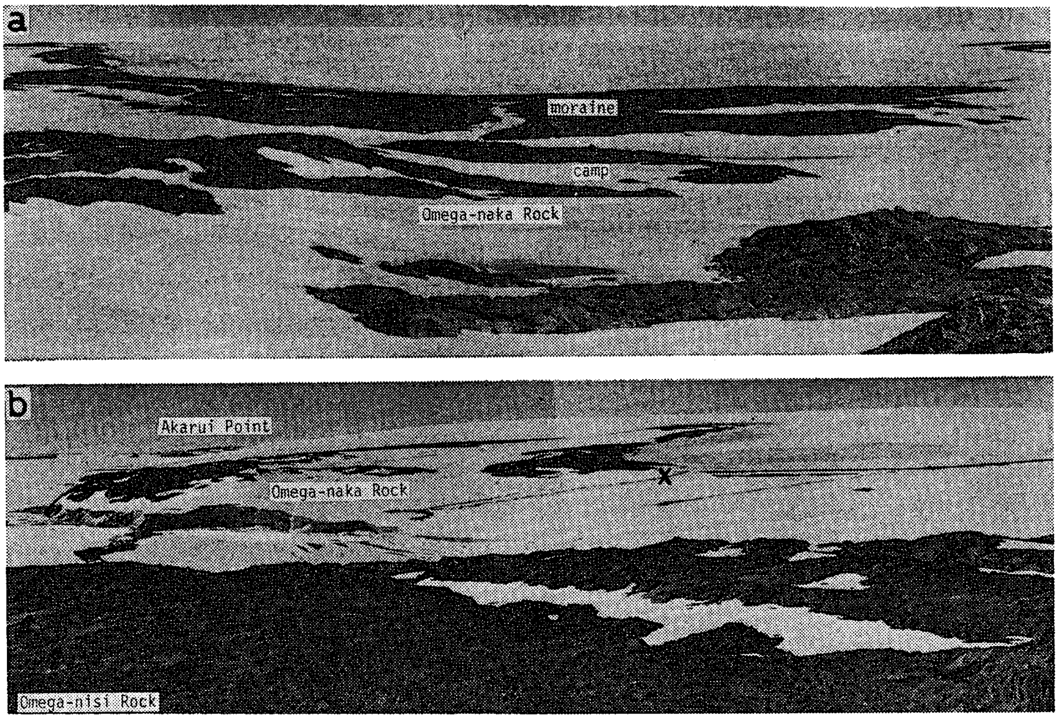

Fig. 10. (*a*) *Numerous rills of meltwater on the slope of marginal zone of the ice sheet.* (*b*) *Meltwater streams.* ×: *Observation station of meltwater stream.*

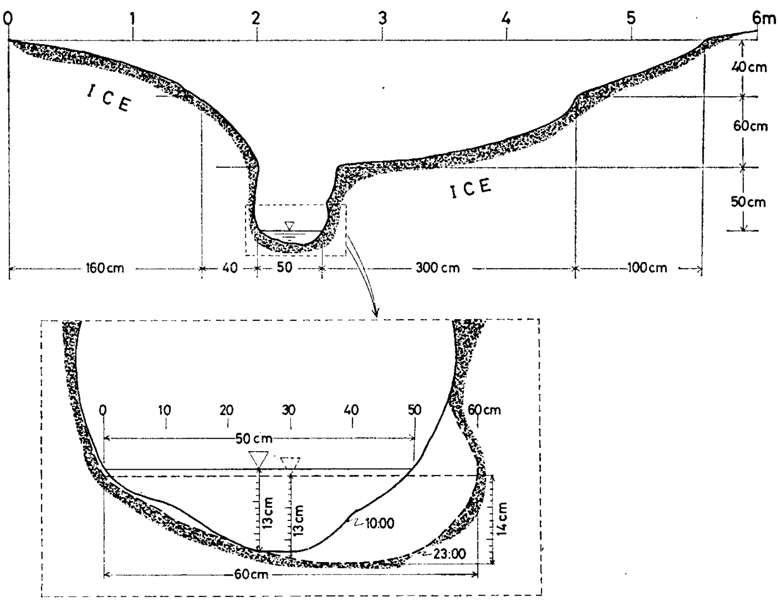

Fig. 11. Cross sections of meltwater stream at the observation station (*shown in Figs. 1 and 10*).

ary 8th 1977 by using an electric current meter. On the ice wall along the stream are found three steps like river terraces (Fig. 11). But it is not known by what process were formed such steps. Snow patches near Syowa Station are most melt from early January to early February (HAYASHI, 1977). Change in water level of Lake Vanda in the Wright Valley, South Victoria Land, shows that the maximum amount of discharge from the Onyx River flowing into Lake Vanda occurred from the end of December to the middle of January (YOSHIDA *et al.*, 1971). Therefore, measurement in Cape Omega (January 8th) must have been carried out at the time of the maximum amount of meltwater flow. Results of measurements are shown in Fig. 12. The cross-sectional areas of stream were measured at 10:00, 23:00 and 24:00, and the values obtained were 0.038 m^3, 0.056 m^3 and 0.056 m^3, respectively (Fig. 11). The total amount of flow of the meltwater stream from 10:00 to 24:00 is calculated to be 5943 m^3. Flow rates of the stream at 01:00 and 09:00 were not measured, though it

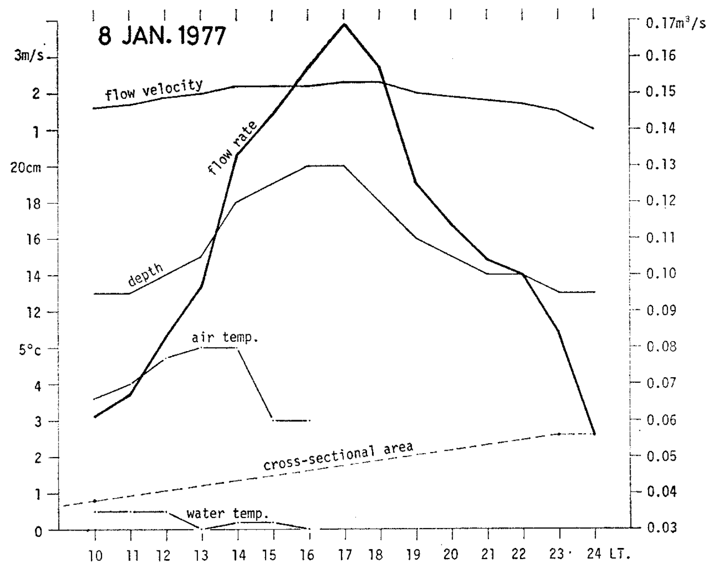

Fig. 12. Hourly change of amount of meltwater at the observation station (shown in Figs. 1 and 11). The flow rate (V m^3/s) at each hour was calculated from the following equation;

$$V = s \cdot v,\ s = \frac{d}{13}\left(0.024 + \frac{0.056 - 0.038}{23 - 10}\ t\right),$$

$$V = \frac{1}{13} \cdot v \cdot d(0.024 + 0.0014\,t).$$

v: flow velocity (m/s) at each hour.
s: cross-sectional area (m^3) at each hour.
d: depth (cm) of the center of stream at each hour.
t: hour.

The flow rate at 24:00 was calculated independently from the above equation since the cross-sectional area at 24:00 was measured.

was apparently larger than 0. Hence the total amount of meltwater flow during 24 hours is larger than 5943 m^3. Namely the total amount of flow per one meltwater stream at that time is estimated roughly at 6×10^3 t/day at least. MORIWAKI (1976) estimated the amount of flow per one meltwater stream to be 15.5×10^3 t/day in Cape Hinode (42°40′E, 68°08′S), assuming the measured flow rate (0.18 m^3/s) at 14:00 on January 2nd 1974 being constant during 24 hours. Diurnal change of flow rate of the meltwater stream occurred obviously in Cape Omega and near Syowa Station (Fig. 12; HAYASHI, 1977). Thus, the amount of meltwater flow in Cape Hinode (15.5×10^3 t/day) was overestimated.

As far as the two examples of measurements in Cape Omega and Cape Hinode are concerned, the amount of flow per one meltwater stream in the marginal zone of ice sheet is estimated in the order of 10^3 t/day at least in the middle of summer. But in this estimation the subsurface flow of meltwater in the ice sheet was excluded (YAMADA, 1975; MORIWAKI, 1976). The duration, density and pattern of meltwater streams in the marginal zone of the ice sheet must be investigated to evaluate the role of meltwater flow in ablation of the ice sheet (YOSHIDA, 1972). A multi-band camera to be used by JARE-21 (1979–1981) will be useful in this survey.

Acknowledgments

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